Modeling the Impact of Drought on Groundwater and Crops

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Overview of Project

1. **Modeling project covering the joint optimization of groundwater levels and cropping in the Central Valley**
2. **Steps include a drought, a groundwater model and a cropping model.**
   - **The drought is imposed with impacts on surface water supply**
   - **Groundwater model determines groundwater level, subject to crop water demand.**
   - **Crop model uses groundwater level, to determine crop acres and crop water demand.**
   - **The linked model determines joint groundwater levels and crop water demands over a multi-period drought.**

Three ways to measure impact drought on groundwater and cropping

1. There are three ways to measure groundwater impacts in droughts. The easy way is to **hold crop water demand constant**.
   - Define drought
   - Estimate decline in groundwater using standard model (C2VSIM).

2. A better approach is to **allow crop fallowing** as groundwater levels fall.
   - Estimate rise in pump costs as groundwater levels fall.
   - Estimate farmer's willingness to irrigate marginal crops with groundwater.
   - When pump costs exceed farmer willingness to pay, crops are fallowed.

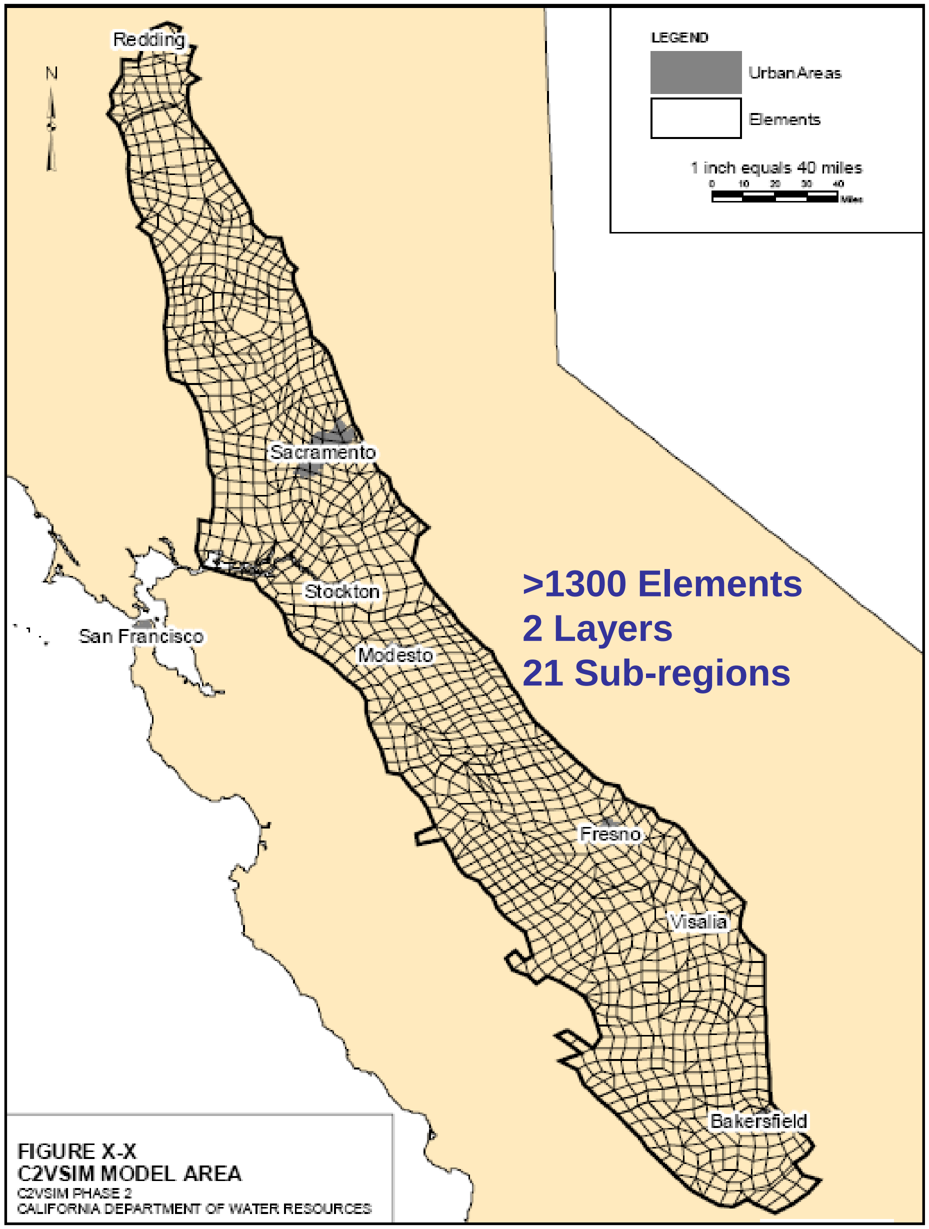
3. The best approach is to **permit crop switching**
   - Estimate crop switching and other water saving practices, across range of groundwater levels, using crop production model (CVPM).
   - Summarize crop switching (etc.) into crop response functions.
   - Integrate crop response functions into the groundwater model (C2VSIM)
   - Estimate changes in groundwater jointly with changes in cropping.

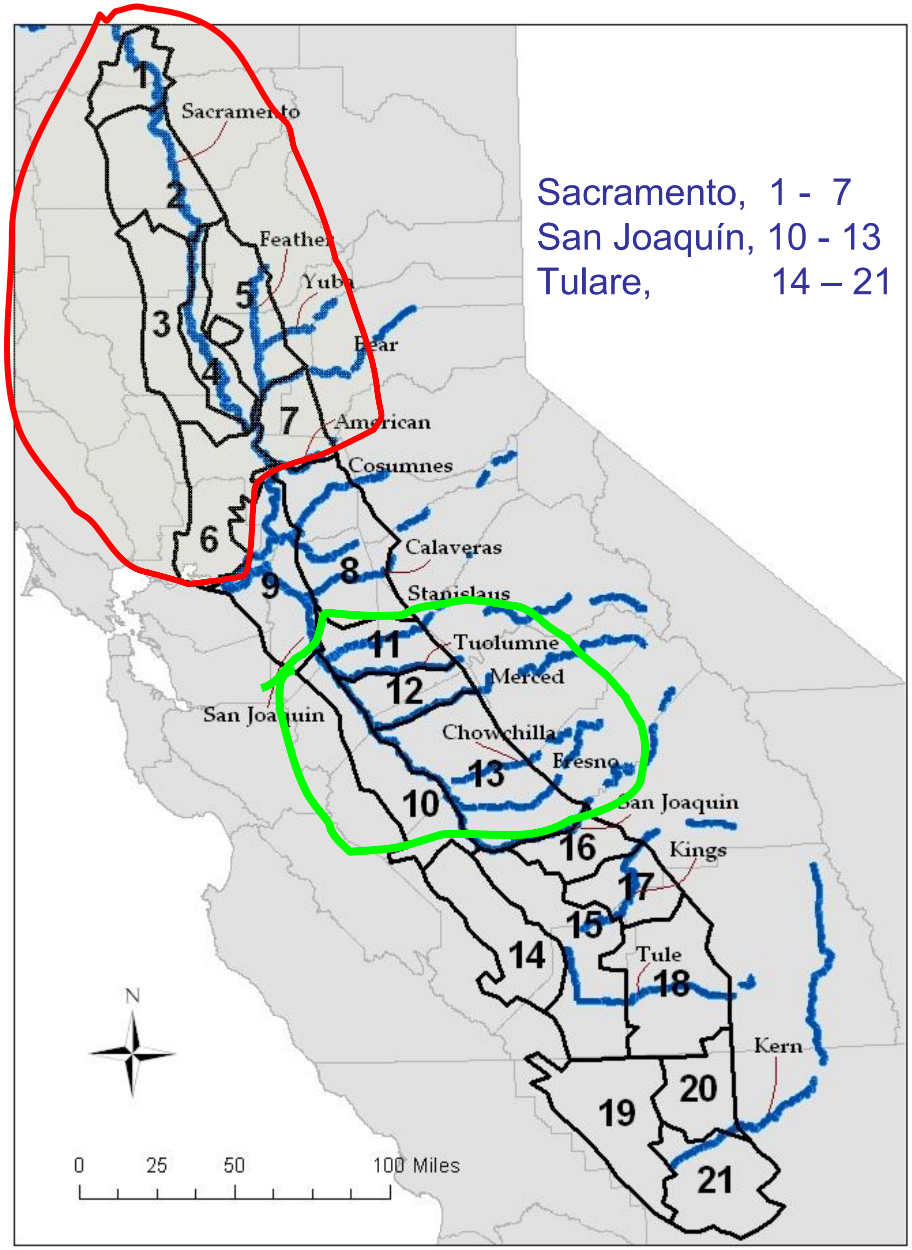
I. Measuring Impacts on Groundwater

No crop limits

- **Use state groundwater model (C2VSIM)**
  - **Simulates groundwater, surface water, groundwater-surface water interactions.**
  - **Pump quantity adjusts to changes in surface deliveries to meet fixed agricultural water demand.**
- **Define drought scenarios**
  - **Indicate decline in surface deliveries across the Central Valley during "defined drought".**
- **Estimate fall in groundwater during defined drought scenarios, using groundwater model.**

The Groundwater Model (C2VSIM)





- Domain: ~ 20,000 square miles

Define the Drought Scenarios

- We divided 1922 - 2002 into normal, dry, and critically dry years.
- Severe drought is 60 years of repeating critically dry years.
  - Average of 36% decline deliveries, “severe drought”
- The light drought is 60 years of repeating dry years
  - Average 10% decline deliveries in “light drought”

Impact Drought on Deliveries

fixed cropping, C2VSIM

	Base Period (maf/y)	**Severe drought impact** (maf/y)
Central Valley	10.82	-3.81
Change(%)		-35%

	Base Period (af/a/y)	**Severe drought impact** (af/a/y)
Sacramento	1.03	-0.23
Eastside	0.01	-0.01
San Joaquin	1.07	-0.44
Tulare	0.57	-0.40
Central Valley	0.85	-0.30
Change(%)		-35%

Deliveries decline 35% in driest years

Impact Drought on Pumping

fixed cropping

	Base Period (ft/y)	Severe drought additional pumping (ft/y)
Sacramento	0.50	0.31
Eastside	0.64	0.12
San Joaquin	0.38	0.58
Tulare	0.37	0.51
Central Valley	0.41	0.41
Change(%)		99%

Pumping increases 99% in driest years

I. Impact Drought on Groundwater

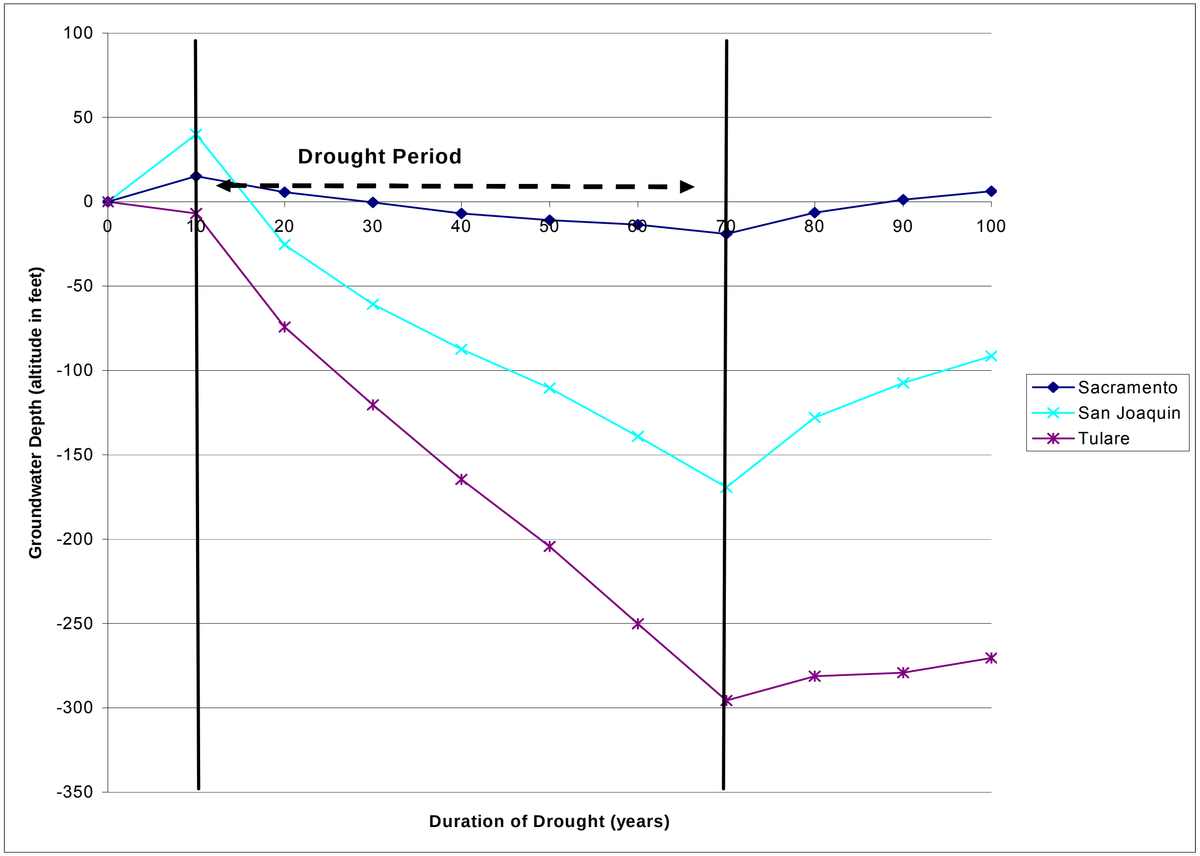
fixed cropping, C2VSIM

	Base Period (af/a/y)	**Severe drought impact** (af/a/y)
Sacramento	-0.07	-0.92
Eastside	-1.67	-1.73
San Joaquin	-1.60	-3.81
Tulare	1.35	-2.99
Central Valley	0.18	-2.26

Groundwater declines almost 3.8 feet per year across San Joaquin Basin

Decline in Groundwater Levels

Severe drought scenario, fixed cropping, C2VSIM



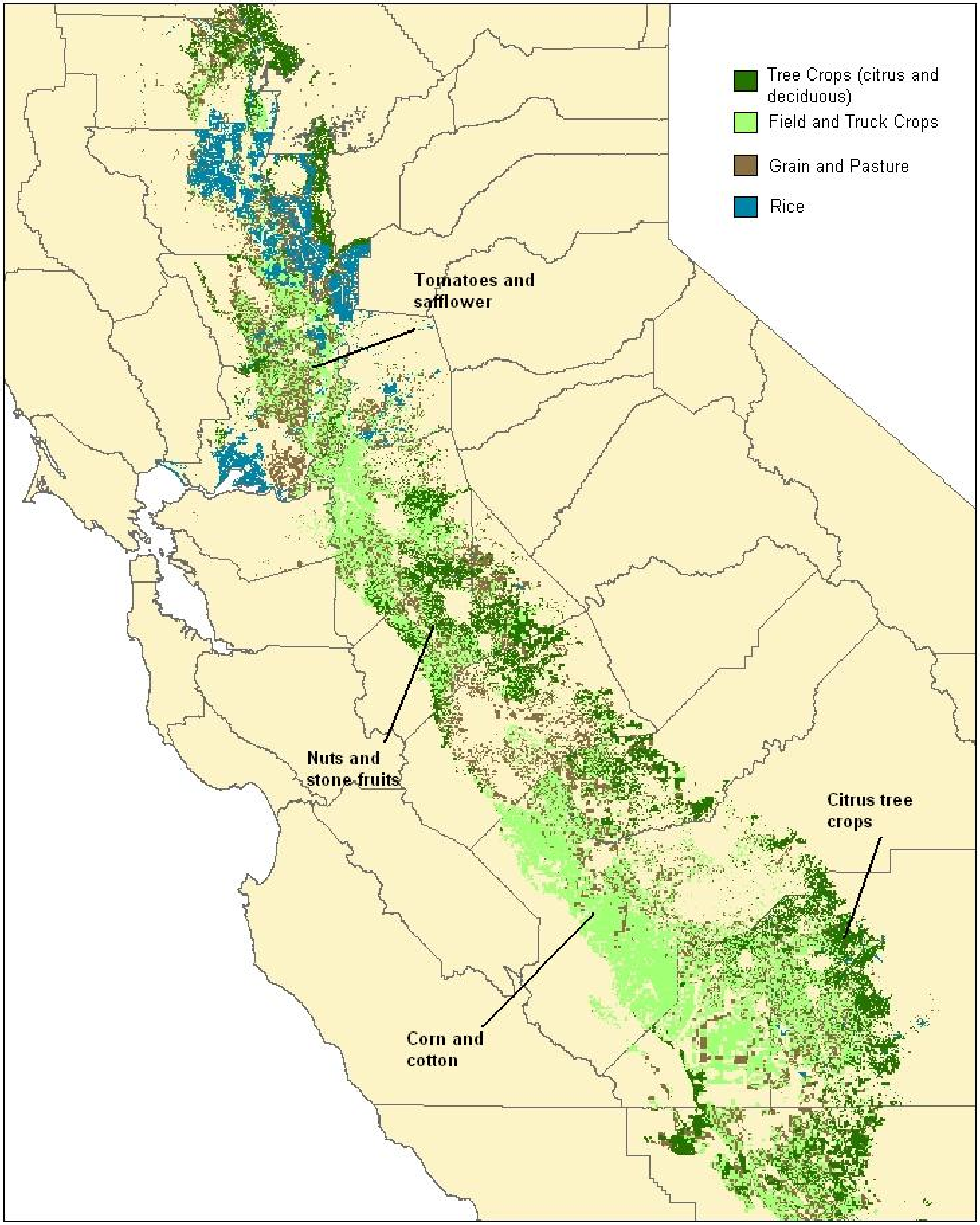
Over 60 years, groundwater levels decline 300 feet in San Joaquin

- **C2VSIM and ALL water allocation models on this scale are only partially verified.**
- **Many empirical parameters are tuned.**

II. Measuring Climate Impacts on Groundwater

Crop fallowing

- Net crop value
  - Crop value determines farmer willingness to pump groundwater
- Depth to groundwater
  - Groundwater depth indicates pump cost.
- Crop groundwater diagram, no crop switching
  - When pump costs exceed willingness to pump, crops are fallowed.



Wide range of crops grown in Central Valley.

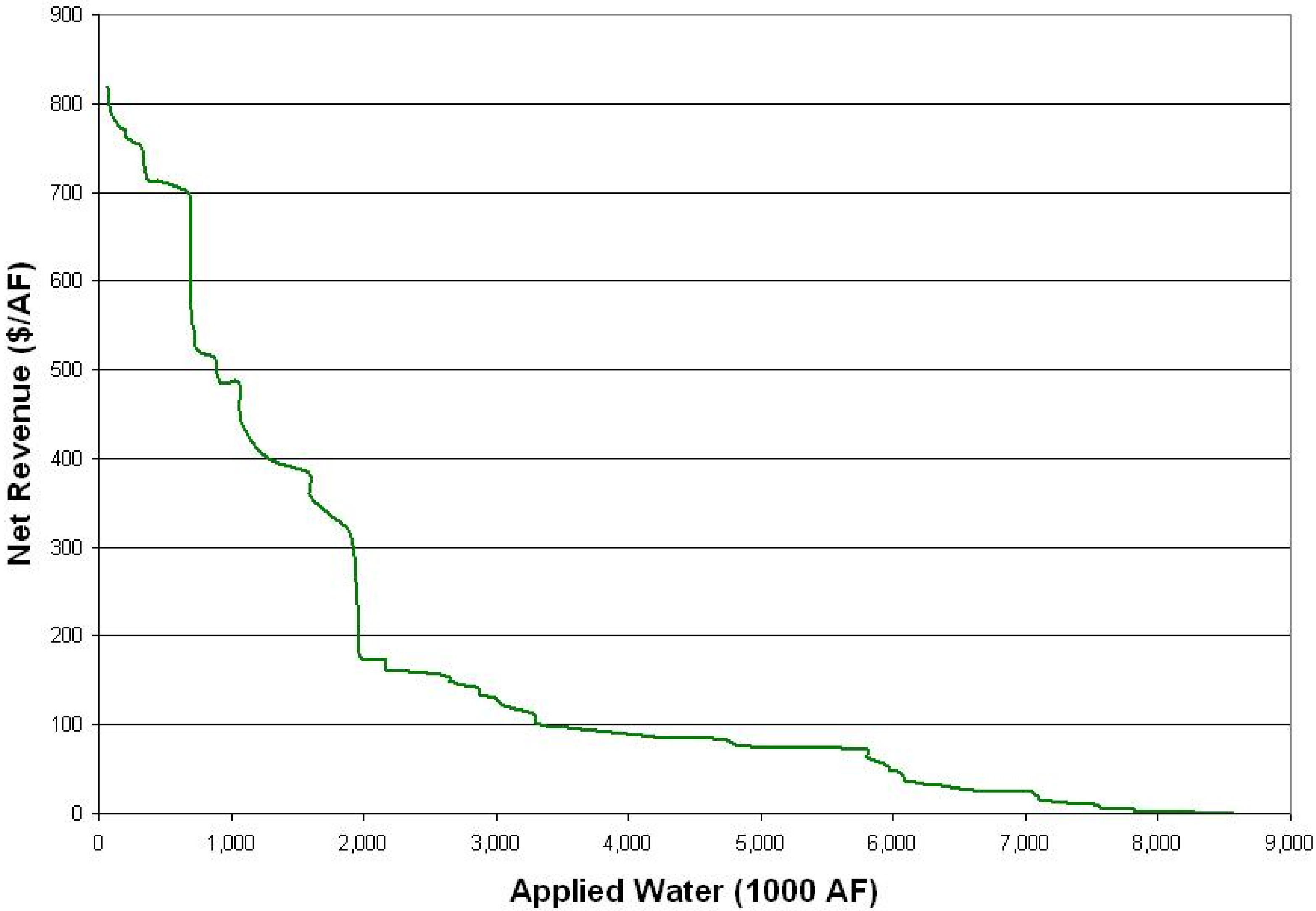
Wide range of values.
Tree crops worth hundreds per acre.
Field crops worth $10-20 per acre foot of water applied.

Water use varies widely.
Rice (5 acft/ac).
Cotton (2 acft/ac)

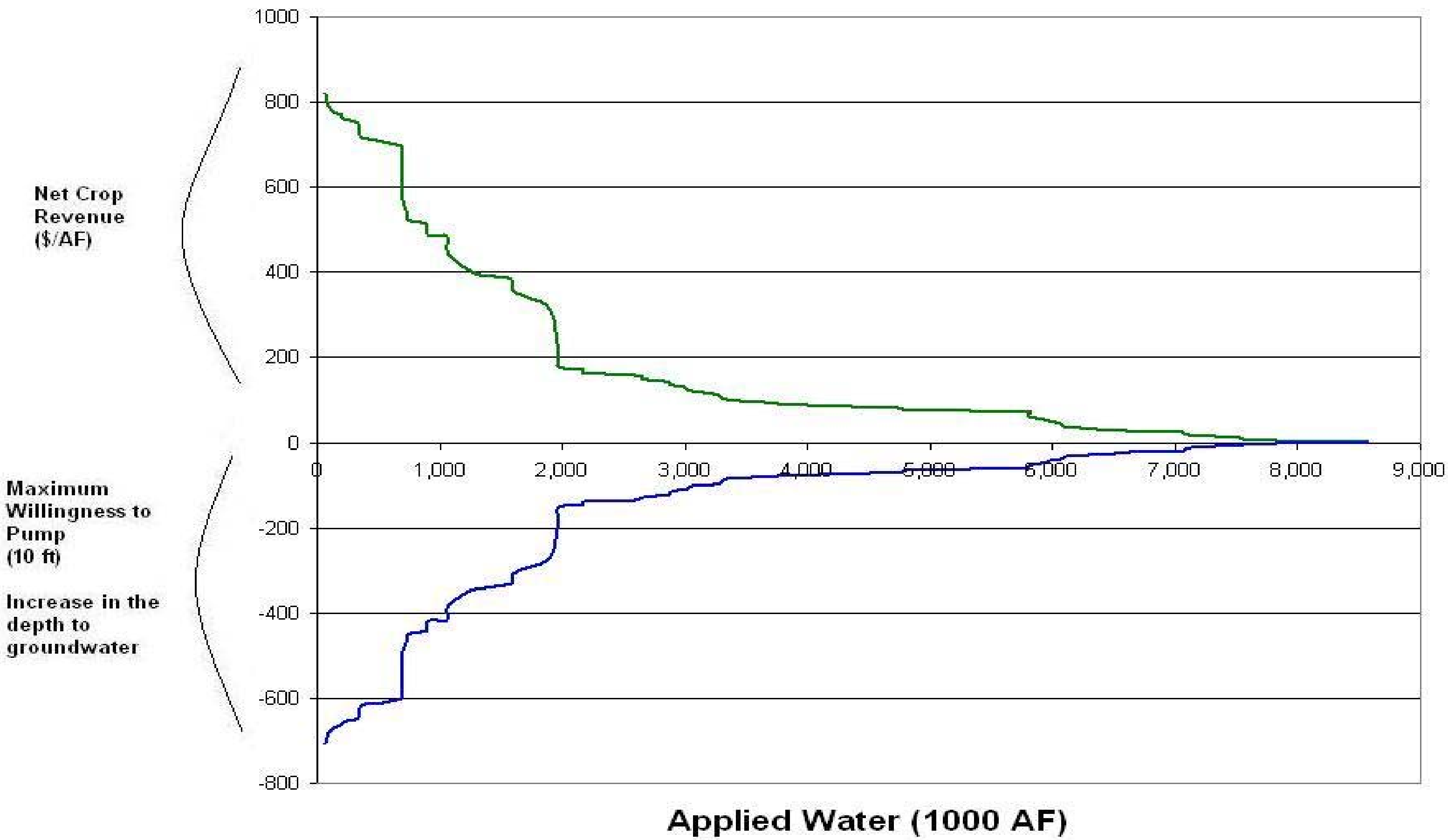
Changes in water costs likely to

Net Crop Value

Tulare Basin, CVPM crop budgets

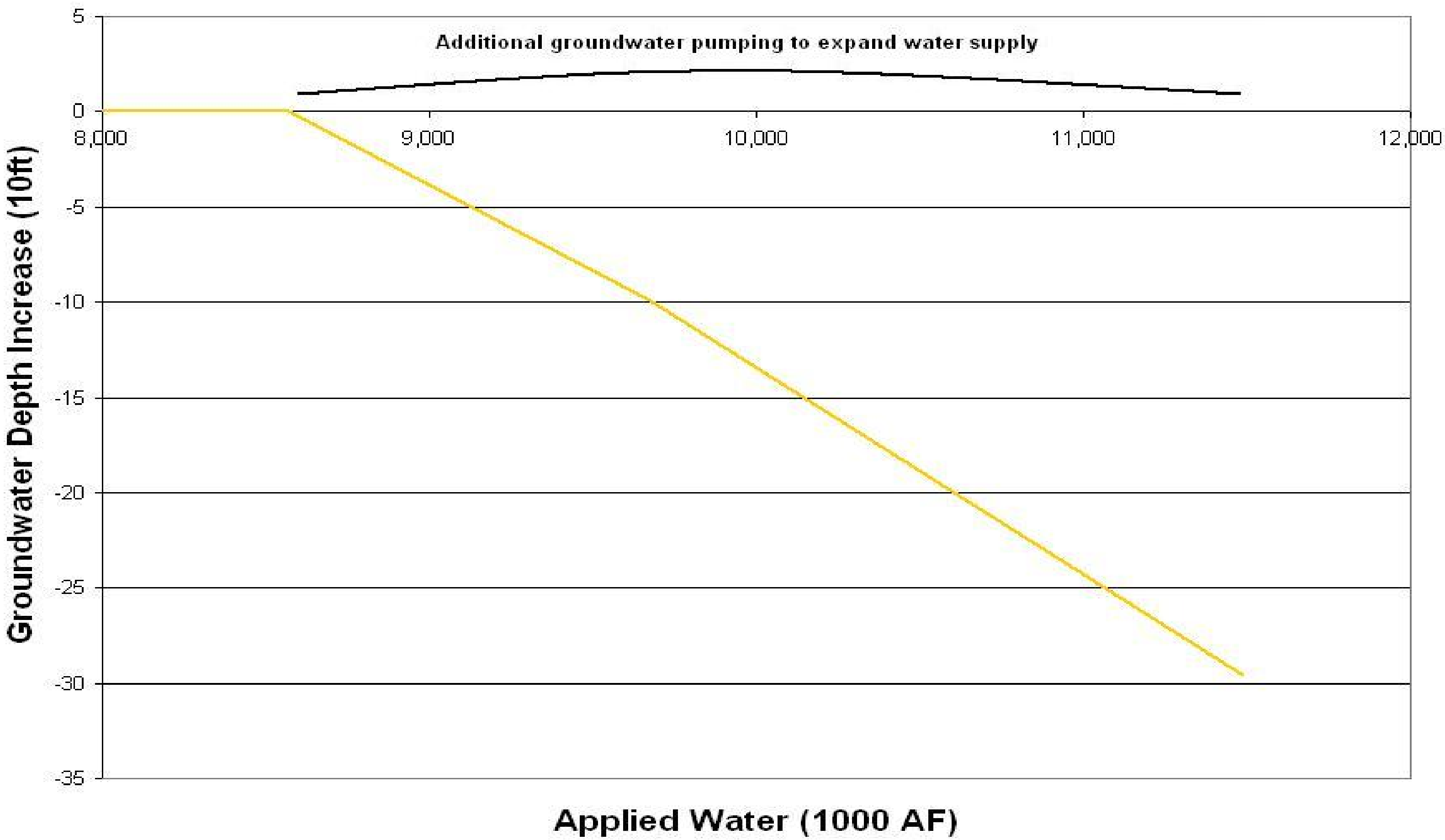


Willingness to Pay for Groundwater



Crop limits to groundwater depth.
Maximum depth willing to pump, inferred @ .08/kWh

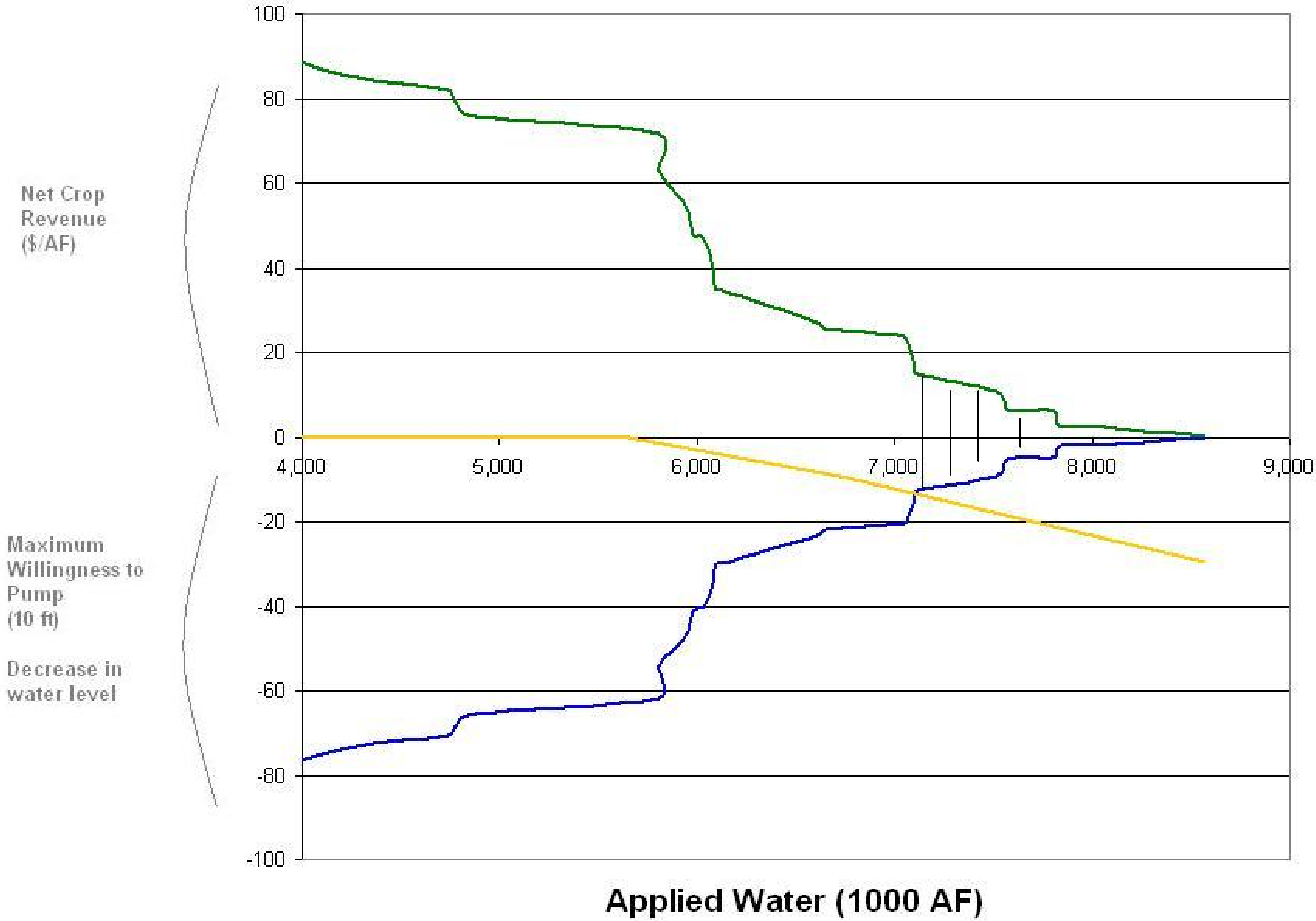
Groundwater Depth, “LR Cost of Pumping”



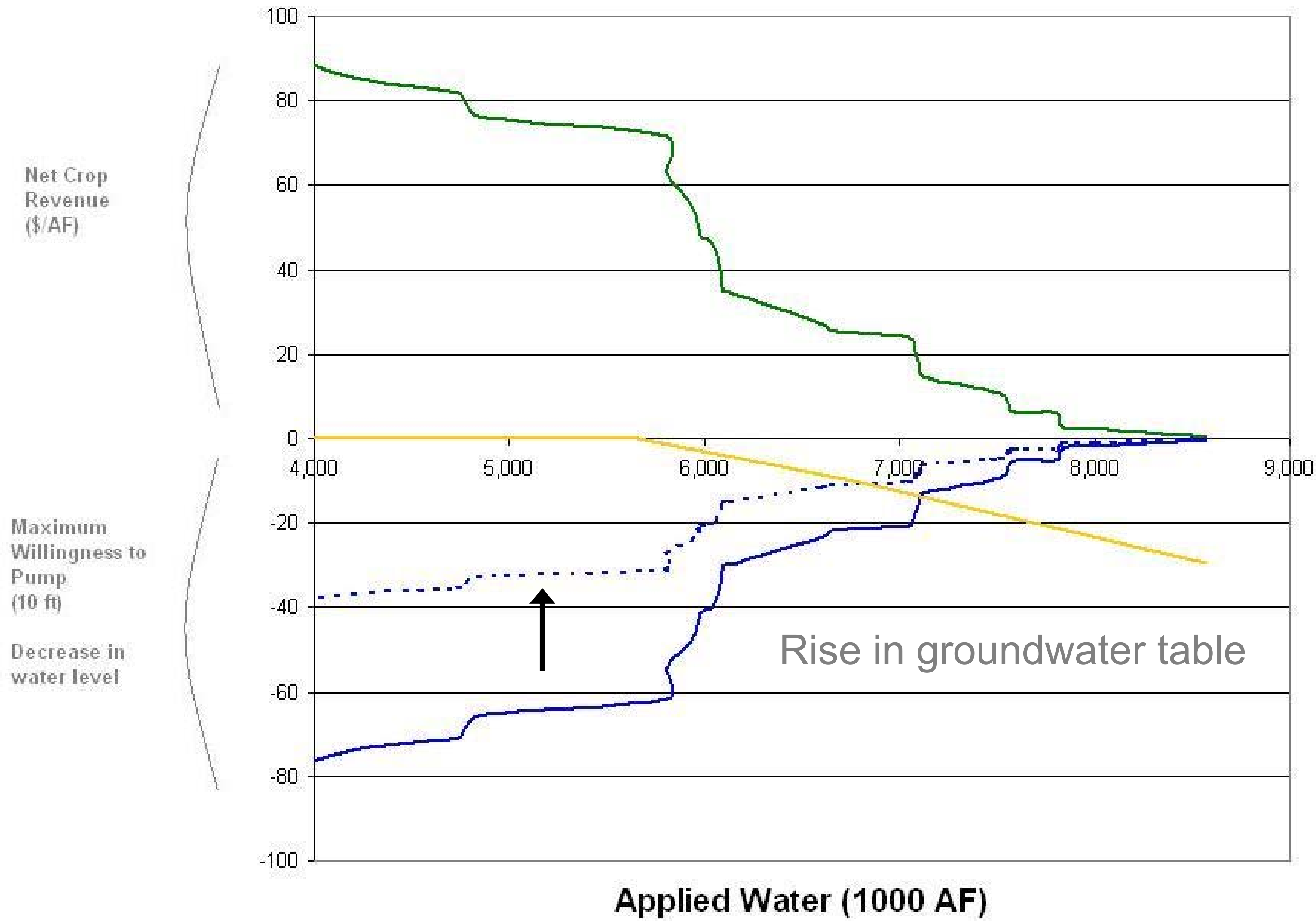
Change in groundwater over given range of pumping.
Severe drought impacts over 60 years.

Equilibrium Groundwater

Where LR cost pumping equals WTP



Impact of Rise Electricity Price



III. Measuring Impacts on Groundwater

Crop switching

- Central Valley Agricultural Production Model (CVPM)
  1. Generate CVPM outputs:
     Crop shares function groundwater depth and deliveries.
  2. Estimate crop share response function.
  3. Measure Accuracy of crop share function
  4. Program response functions into groundwater model (C2VSIM).
- Groundwater model, with response function, estimates changes in groundwater level jointly with changes in cropping.

1. Generate CVPM outputs

(long run and short run mode)

Generate multiple CVPM model outputs:

- base water supply and groundwater depth,
- 10% -20% decrease from base water supply
- 100 –200 foot drop in the groundwater depth
- Model runs provide multiple estimates of crop shares across a range of regional, water supply and groundwater depth inputs.

1. Generate CVPM Outputs

						Cereal	Orchard	Pasture	Rice	Row	Fallow
groundwater depth	**percent surface supply**	**reg3**	**reg3b**	**reg4**	**reg5**	**percent**	**percent**	**percent**	**percent**	**percent**	**percent**
110	1	0	1	0	0	25%	32%	18%	11%	14%	0%
160	0.8	0	1	0	0	25%	32%	17%	11%	14%	2%
160	0.85	0	1	0	0	25%	32%	17%	11%	14%	2%
160	0.9	0	1	0	0	25%	32%	17%	11%	14%	2%
160	0.95	0	1	0	0	25%	32%	17%	11%	14%	2%
210	0.8	0	1	0	0	24%	32%	17%	10%	14%	4%
210	0.85	0	1	0	0	24%	32%	16%	10%	14%	4%
210	0.9	0	1	0	0	24%	32%	16%	10%	14%	4%
210	0.95	0	1	0	0	24%	32%	16%	10%	14%	4%
260	0.8	0	1	0	0	24%	32%	16%	10%	14%	6%
260	0.85	0	1	0	0	24%	32%	15%	10%	14%	6%
260	0.9	0	1	0	0	24%	32%	15%	10%	14%	6%
260	0.95	0	1	0	0	24%	32%	15%	10%	14%	5%
310	0.8	0	1	0	0	23%	32%	15%	10%	14%	7%
310	0.85	0	1	0	0	23%	32%	15%	10%	14%	7%
310	0.9	0	1	0	0	23%	32%	15%	10%	14%	7%
310	0.95	0	1	0	0	23%	32%	15%	10%	14%	7%
60	1	0	0	1	0	32%	11%	3%	32%	22%	0%
75	1	0	0	0	1	10%	34%	7%	46%	3%	0%
85	1	1	0	0	0	16%	6%	9%	48%	21%	0%

2. Estimate Crop Share response function

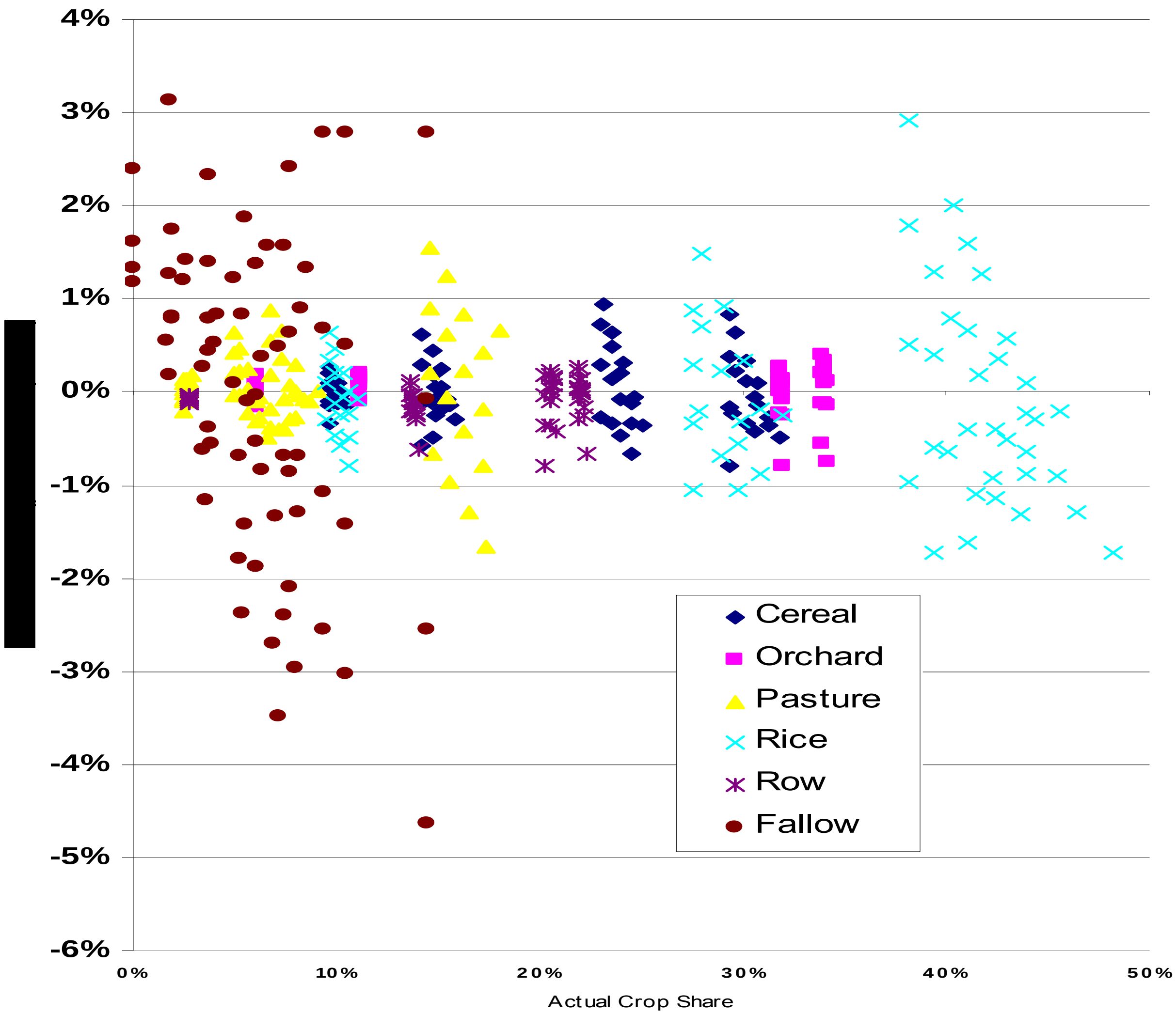
(regional dummy variables, long run mode)

	Cereal B1	Orchard B2	Pasture B3	Row B4	Rice B5
Depth (ft)	-0.004	-0.004	-0.005	-0.005	-0.004
Percent supply	6.225	5.992	6.799	6.568	5.999
region 3	-1.287	-2.473	-1.569	0.609	-0.414
region 4	-0.130	-1.412	-2.201	0.681	0.111
region 5	-1.361	-0.405	-1.518	0.931	-2.074
constant	-2.683	-2.235	-3.481	-3.817	-3.074

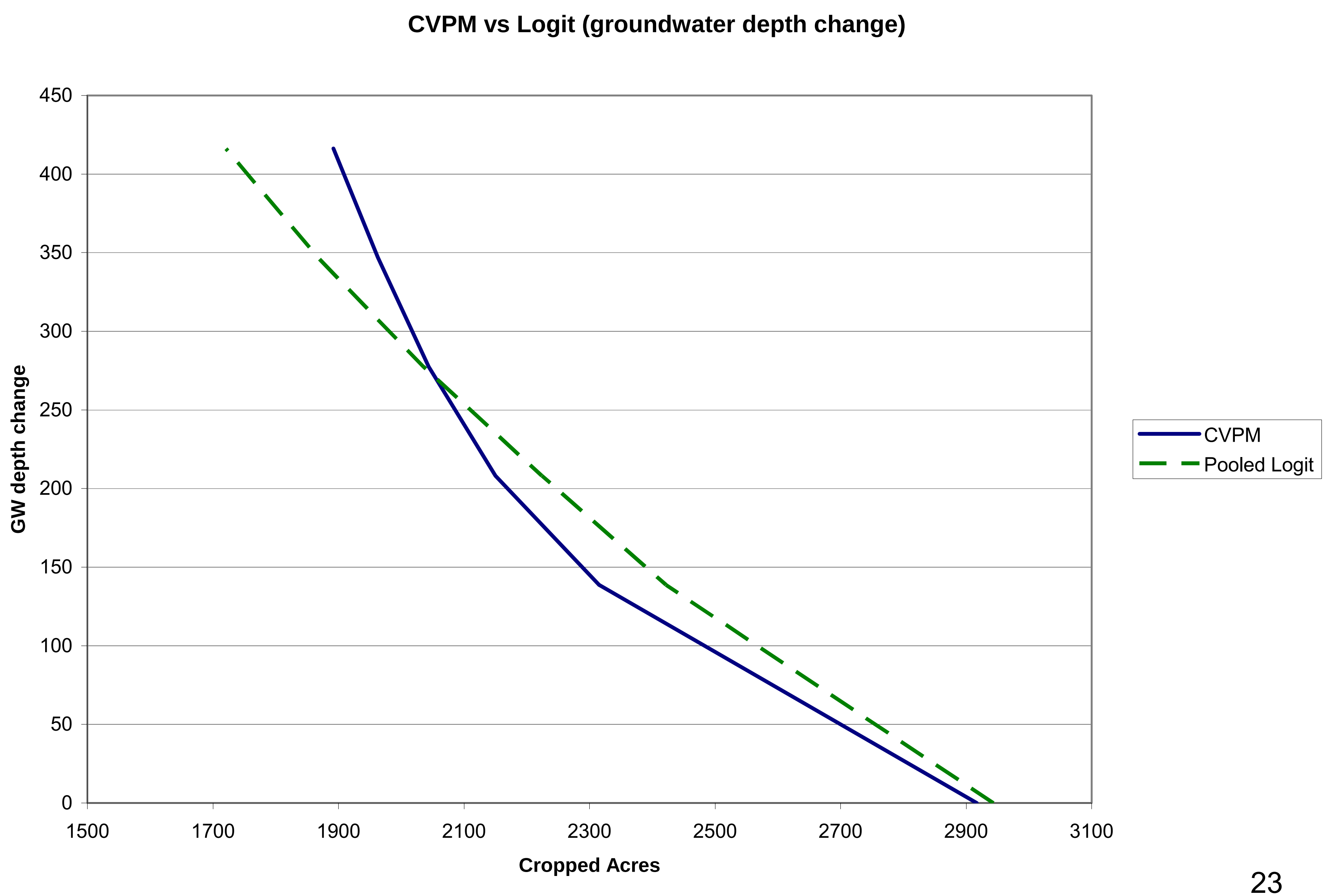
Obs.	173597
Log Likelihood	-2.592
Outcome	Fallow is the comparison crop.

3. Accuracy of Response Function, Crop Shares

Estimated crop shares within 1-3% of CVPM crop shares



3. Accuracy of Response Function: Impact Depth on Crop Acres
Logit vs CVPM acreage change estimates



Accuracy of Response Function—historical period

Model predicts rise fallowing, drop pasture in ‘89-’93

Historic Crop Shares

Year	**Cereals**	**Orchard**	**Pasture**	**Rice**	**Vegetables**	**Fallow**
1989	24.0%	21.5%	17.5%	33.9%	3.1%	0.0%
1990	26.3%	21.7%	16.9%	30.7%	3.0%	0.9%
1991	22.8%	22.6%	18.7%	26.1%	2.3%	5.5%
1992	22.4%	24.1%	17.9%	31.2%	1.6%	2.0%
1993	25.5%	25.2%	20.0%	37.8%	2.0%	-7.6%

Predicted Crop Shares

Year	**Cereals**	**Orchard**	**Pasture**	**Rice**	**Vegetables**	**Fallow**
1989	23.7%	21.2%	17.4%	33.6%	3.1%	1.0%
1990	23.8%	21.6%	17.0%	33.2%	3.1%	1.3%
1991	23.7%	22.5%	15.0%	30.8%	3.2%	4.7%
1992	23%	23%	14%	30%	3%	7%
1993	24%	22%	16%	32%	3%	3%

Estimation Error, Predicted Minus Historic Crop Shares

Year	**Cereals**	**Orchard**	**Pasture**	**Rice**	**Vegetables**	**Fallow**
1989	-0.2%	-0.2%	-0.2%	-0.3%	0.0%	1.0%
1990	-2.5%	-0.1%	0.0%	2.5%	0.1%	0.4%
1991	0.9%	-0.1%	-3.7%	4.7%	0.9%	-0.8%
1992	0.9%	-1.5%	-3.7%	-1.5%	1.6%	4.9%
1993	-1.6%	-2.9%	-4.2%	-6.0%	1.2%	10.7%

Source:
Historic crop shares from County Agricultural Commissioner Reports for Glenn and Colusa County.
Predicted shares from logit model crop share equations, calibrated to fit Glenn and Colusa Coutny 1989 crop shares

Impact Climate Change Groundwater Levels

Early modeling results

- The Department of Water Resources included our crop response functions into the groundwater model (C2VSIM).

- Estimate 2070 severe drought groundwater levels with the response functions.
    - Sacramento levels fall almost 50 feet.
    - Tulare Basin levels fall over 200 feet
        - 5-20% less than levels estimated assuming fixed agricultural demand.

III. Impact Drought on Groundwater

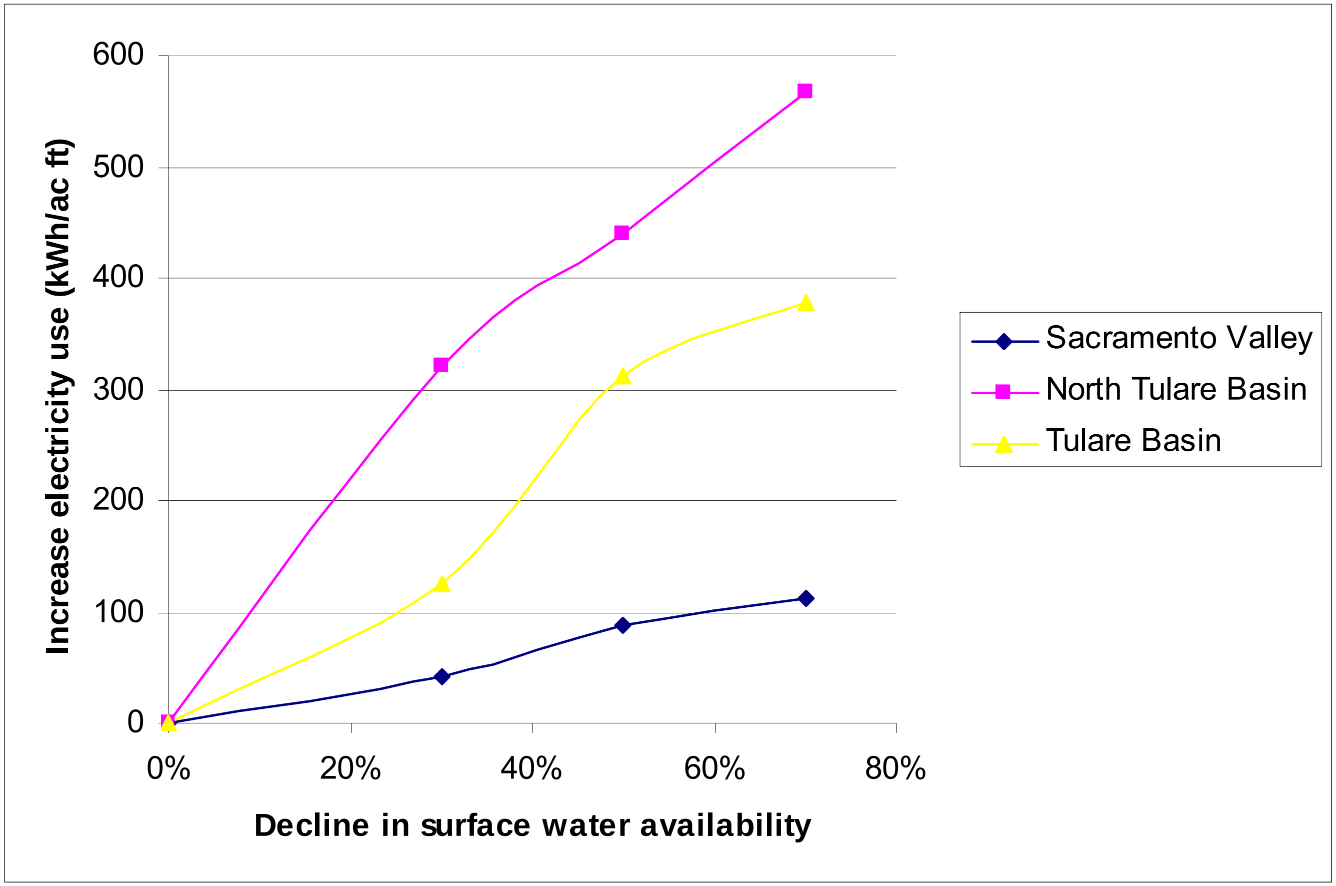
adjustable cropping, C2VSIM

	Base Period (ft/y)	**Variable crop severe drought impact** (ft/y)	**Fixed crop severe drought impact** (af/a/y)
Sacramento	-0.07	-0.73	-0.92
Eastside	-1.65	-1.48	-1.73
San Joaquin	-1.36	-2.59	-3.81
Tulare	1.27	-2.28	-2.99
Central Valley	0.20	-1.68	-2.26

Variable crop model shows smaller rate of decline in groundwater.

Drought Impact on Electricity Use

Increase in electricity use as function of drought severity, selected sub regions.



Conclusion and Future Work

- Two stage logit modeling of CVPM
- Estimate long run crop shares using the long run logit (stage one equation)
- Estimate short run crop shares with a second stage equation, where the the RHS explanatory variables include long run crop shares.
- To estimate impacts with this logit equation, need four water supply inputs--base case long run and short run supply--to estimate long and short run base crop shares; and long and short run impact supply--to estimate impacts.

Formulation of the logit equation

Let *i* and *j* index crops and let *r* and *s* index regions. A multinomial logit model predicts the share of acreage in each region planted with a given crop. The share of land planted in crop *i* and region *r* is given by:

$$\alpha_{ir} = \frac{e^{x_r \beta_{ir}}}{1 + \sum_j e^{x_r \beta_{jr}}}$$

where x_r is a vector of regional explanatory variables and β_{ir} is a vector of estimated coefficients. The summation in the denominator includes a term for each of the crops (except the reference crop), including crop *i*. Applied water **per acre** for crop *i* and region *r* is given by:

$$a_{ir} = x_r \gamma_{ir}$$

where x_r is again a vector of explanatory variables which may vary by region and γ_{ir} is a vector of estimated coefficients which may vary by region and crop.

2. Estimate Crop Share Response Function

Fallow	P_0	$\Pr(y=0)=\dfrac{1}{1+e^{XB_1}+e^{XB_2}+e^{XB_3}+e^{XB_4}+e^{XB_5}}$
Cereal	P_1	$\Pr(y=1)=\dfrac{e^{XB_1}}{1+e^{XB_1}+e^{XB_2}+e^{XB_3}+e^{XB_4}+e^{XB_5}}$
Orchard	P_2	$\Pr(y=2)=\dfrac{e^{XB_2}}{1+e^{XB_1}+e^{XB_2}+e^{XB_3}+e^{XB_4}+e^{XB_5}}$
Pasture	P_3	$\Pr(y=3)=\dfrac{e^{XB_3}}{1+e^{XB_1}+e^{XB_2}+e^{XB_3}+e^{XB_4}+e^{XB_5}}$
Rice	P_4	$\Pr(y=4)=\dfrac{e^{XB_4}}{1+e^{XB_1}+e^{XB_2}+e^{XB_3}+e^{XB_4}+e^{XB_5}}$
Row	P_5	$\Pr(y=5)=\dfrac{e^{XB_5}}{1+e^{XB_1}+e^{XB_2}+e^{XB_3}+e^{XB_4}+e^{XB_5}}$